Computational Creativity Theory: Inspirations behind the FACE and the IDEA models

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Abstract

We introduce two descriptive models for evaluating creative software; the FACE model, which describes creative acts performed by software in terms of tuples of generative acts, and the IDEA model, which describes how such creative acts can have an impact upon an audience. We show how these models have been inspired both by ideas in the psychology of creativity and by an analysis of acts of human creativity.

Introduction

The Computational Creativity (CC) community needs concrete measures of evaluation to enable us to make objective, falsifiable claims about progress made from one version of a program to another, or for comparing and contrasting different software systems for the same creative task. There are two notions of evaluation in CC: (*i*) judgements which determine whether an idea or artefact is valuable, and (*ii*) judgements to determine whether a system is acting creatively. Our thesis is that ideas from the psychology of creativity can help us to develop such measures, and we demonstrate this via our two models, which form a framework to aid us in the development and evaluation of creative software. Note that while we draw on psychology and examples of human creativity for inspiration, our goal lies squarely within CC – *to provide a means of formalising some aspects of computational creativity* – we by no means claim that our models would be appropriate for evaluating human creativity. The main test and value of such models lies in their applicability to CC systems: we defer such application to a sister paper [4].

The FACE model

The FACE model assumes eight kinds of generative acts, in which both processes (p) and artefacts (g) are produced:

F^p: a method for generating framing information
F^g: an item of framing information for A/C/E $^{p/g}$
A^p: a method for generating aesthetic measures
A^g: an aesthetic measure for process or product
C^p: a method for generating concepts
C^g: a concept
E^p: a method for generating expressions of a concept
E^g: an expression of a concept

Any particular creative episode can be expressed in terms of at least one of these components (it may well be the case that not all of the components will be present). In order to cover as many creative acts as possible, we assume only that there must be something new created for the question of creativity to arise. This could be very small, a brush stroke of an artist, an inference step by a mathematician, a single note in a piece of music. Thus, we avoid the thorny issue of where an act of creation starts and important questions about where on the scale from basic to sophisticated an act must be, to be judged creative, can be postponed. This position is in line with the argument by Cardoso *et al.*, that "To achieve human levels of computational creativity, we do not necessarily need to start big, at the level of whole poems, songs, stories or paintings; we are more likely to succeed if we are allowed to start small, at the level of simple but creative phrases, fragments and images" [3, p. 17].

The IDEA model

In order to assess the impact of the creative acts performed by software, we assume an (I)terative (D)evelopment-(E)xecution-(A)ppreciation cycle within which software is engineered and its behaviour is exposed to an audience. The IDEA descriptive model recognises that in some creative tasks, the invention of measures of value forms a part of the creative act. Hence usual models of value are abandoned in favour of describing the impact that creative acts can have. The model introduces some simplifying assumptions about the nature of (i) the software development process (ii) the background information known in general, known by the programmer, and given to the software, and (iii) the nature of the audience who assess the impact of the creative acts performed by the software. Using these simplifications, the model comprises two branches. The first of these is a descriptive model for the stage of development that software is in, in terms of how close its creative acts are to those performed by the programmer in engineering the software, and how close they are to those that have been performed by community members in the wider context in which the software works. The second branch uses the notion of an ideal audience who can perfectly assess both their personal hedonistic value of a creative act, and the time they are prepared to spend interpreting the act and its results. These measures are used to capture certain notions that are usually associated with impact. In particular, notions such as shock (when audience members tend to take an instant dislike to a creative act), acquired taste (when audience members tend to spend a long time in eventually positively assessing a creative act) and opinion splitting (when a creative act is particularly divisive) are formally developed.

The creation of prime numbers

The many aspects which contributed to the creation and appreciation of the concept of prime number have inspired our development of the FACE model. These include inventing the concept itself and inventing ways of developing new concepts in number theory. Along with the concept definition we find examples, or expressions, of the concept, in the form of numbers which are either known to be prime (*eg.* $2, 3, 5, 7$), known not to be prime (*eg.* $4, 6, 8, 9$),[1] or have an unknown status (*eg.* $2^{13466917} + 1$) and algorithms for determining whether a given number is prime have been developed, such as the Sieve of Eratosthenes, as well as ways of generating further primes. The concept of primes was embedded into number theory by developing specialisations (*eg.* Cuban, happy, illegal and lucky primes) and theorems and conjectures (*eg.* the fundamental theorem of arithmetic); and into the wider field of mathematics as uses for primes have been found in group and ring theory, cryptography, and so on, as well as its application to other areas of human experience (*eg.* Messiaen used prime numbers to create ametrical music). In addition to actually developing such concepts, theorems and applications, we can create techniques for developing them, *eg.* the use of analogical reasoning to create analogous concepts in other areas of mathematics. We also evaluate the concept (primes are considered to be the "basic building blocks" of the natural numbers) and suggest new ways in which to make such a judgement. We break this complex story down into the FACE components below:

FACE	Prime numbers
F^p:	Ways in which theorems involving primes can be found
F^g:	Theorems involving primes, which embed the concept within the field of number theory
A^p:	Ways in which which we judge the value of concepts in number theory (for instance, their applicability and use in multiple mathematical domains)
A^g:	Judgements on the value of the concept of prime number
C^p:	Ways of finding new concepts in number theory
C^g:	The concept of a prime number
E^p:	Algorithms for determining whether a given number is prime or not (for instance the Sieve of Eratosthenes)
E^g:	Numbers with an evaluation as to whether they are prime

The creation of upsidedowns

In [3], Cardoso *et al.* describe *The Upsidedowns of Gustav Verbeek*. These are panels which tell a story up to a half way point, the continuation of which then appears almost magically when one turns the panels upside down. We show another example of this type in Figure 1. In terms of our model, starting with the artefact level, we could describe the final piece of art as an expression of the concept E^g; the concept C^g as the constraint that the picture must make sense when upside down (and fit into the story); the aesthetic A^g as the idea of art having multiple meanings when viewed from multiple perspectives; and the framing F^g being the contextual history of this genre of art, the motivation, justification, etc. At the process level, E^p is the generation of methods for producing expressions of art which have a different meaning when viewed upside down (for example, birds flying in the sky can double as waves in the sea, or a hat on one's head can double as a mouth on one's face); C^p represents methods for generating new perspectives from which the art might make sense (other examples include rotating $90°$ rather than $180°$); methods for generating the aesthetic of art having multiple meanings when viewed from multiple perspectives would be A^p (another example would be the aesthetic of art having multiple meanings when viewed from a single perspective); and F^p would be methods for generating new motivations, justifications, and so on.

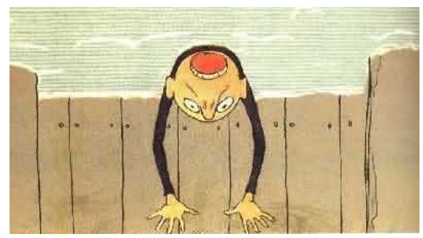

Figure 1: A man coming out of the water – turn upside down to see the same man drowning.

Not all of these aspects may be present in a single act of creativity, and they may be performed by different parties. We can express the upsidedowns as follows:

FACE	Upsidedowns
F^p:	Methods for generating the contextual history of this genre of art
F^g:	The contextual history of this genre of art, motivation, justification, etc.
A^p:	Methods for generating the idea of art having multiple meanings when viewing from multiple perspectives
A^g:	The idea of art having multiple meanings when viewing from multiple perspectives
C^p:	Methods for generating new perspectives from which the art might make sense
C^g:	The constraint that a picture must make sense when upside down
E^p:	Methods for generating expressions of art which have a different meaning when viewed upsidedown
E^g:	Expressions of art which have a different meaning when viewed upsidedown (see figure 1)

Lessons from psychology

There is much work on creativity and little cross-fertilization between fields. In particular, the relationship between CC and the psychology of creativity (in Europe at least) has been oddly disjointed: this is a waste, and our models constitute one attempt to embed various aspects of creativity

[1] Whether 1 should be considered prime is still debated today.

research from psychology into a CC context. Simonton [22] identifies four perspectives in basic research in psychology on the nature of creativity: cognitive psychologists are concerned with mental operations which underlie the creative process; developmental psychologists investigate circumstances which contribute to creative growth; differential psychologists focus on individual differences; and social psychologists investigate sociocultural environments which shape or favour creative activity. Of most relevance to CC are Simonton's first and final categories. The first is the most obvious and much work in CC is motivated by giving a computational representation of mechanisms which can underlie creative behaviour: these may be cognitive or otherwise, depending on the motivation of the CC researcher. The final category is far less common in CC, although work such as that by Saunders [21] has demonstrated its relevance to the CC community. Our models are thus inspired by ideas in these two areas.

Types of creativity

Despite being notoriously difficult to define, researchers have distinguished different types of creativity. These often include some sort of conceptual space, which is an area of work defined culturally by a set of rules and approaches into which individuals are socialised as they master the skills of their field. Some individuals will produce work which violates the rules but is considered by the community to be highly creative, and new work produced according to a new set of rules then becomes the standard for that domain. Csikszentmihalyi [5] distinguishes between little-c creativity which might be within a cultural paradigm and includes everyday, mundane creativity which is not domain-changing, and big-C creativity, which is a rare, eminent creativity in which a problem is solved or an object created that has a major impact on other people and changes the field. Boden [2] draws a similar distinction in her view of creativity as search within a conceptual space, where exploratory creativity searches within the space, and transformational creativity involves expanding the space by breaking one or more of the defining characteristics. Boden also distinguishes between psychological (P-creativity) and historical creativity (H-creativity), concerning ideas which are novel with respect to a particular mind, or the whole of human history. In our FACE and IDEA models we have tried to be sufficiently general so as to capture each of these three types of creativity.

There are some controversies in creativity research regarding how general creativity is. For instance, there is disagreement over whether everyday creativity involves the same processes as eminent creativity [11; 27]. Another common debate (also heard at CC conferences) concerns whether creativity is domain specific [1], and in particular whether it is the same phenomenon in the arts as in science. While most investigators assume that there are a small number of cognitive operations which underlie creativity in diverse domains, Simonton [22] notes that it is also possible that no processes are unique to creativity, or that there are no processes which are present in every instance of creativity. There is also debate on where creativity starts, and which, of the different types, is *more* creative. We occupy a comfortable vantage point on the fence, attempting to create a framework which is general enough to capture all aspects. Specific claims can then be expressed and tested in terms of our models.

The distinction between process and product

The distinction between a product or idea and the processes used to create it is a common one in psychology. Torrance argues that creativity is a combination of person, process and product, seeing a fine line between studying processes and product (reported in [25]). Maher *et al.* point out that "A creative process is one in which the process that generates the design is novel, and a creative product is when we evaluate the result of the design process as being novel" [15]. Much work in creative cognition research seeks to understand the mental representations and processes underlying creative thought. Examples of processes include Finke *et al.*'s Geneplore model [7], in which mental processes such as retrieval, association, transformation, analogical transfer, categorical reduction, and so on, might enter phases of creative invention. Conceptual combination, in which concepts are combined to yield emergent features, is another process thought to be important for creative behaviour, and this process is frequently mentioned in historical accounts of creative accomplishments (see [13; 2]). Analogical reasoning, in which structured knowledge from a familiar domain is applied to a novel or less familiar one, is also thought to be a process with a special link to creativity [10].

There is also justification from historical case studies of creativity for considering a process to be the creative output of interest. For example, consider young Euler's discovery of Arithmetic Series, in which he and his classmates were told to add up all the numbers between 1 and 100. Other pupils arrived at the answer 5050, but everyone except Euler laboriously added each of the numbers individually. Euler realised that if they were written in ascending order and then underneath in descending order, the sum of each of the pairs was 101, and there were 100 pairs. Therefore twice the required sum was 10100, and the answer was 5050. As in the example of the Basel problem described below, there are (at least) two interesting creative outputs: the expression 5050 and the process by which the expression is generated, $S_n =$ sum to n terms $= \frac{n*(first+last)}{2}$. This example shows the importance of a generative process for evaluations of creativity – much more so than the Basel problem, since the expression $\frac{\pi^2}{6}$ was itself H-creative, whereas Euler's solution 5050 was only P-creative. We can break it down as follows:

FACE	**Euler Problem**
F^p:	–
F^g:	Embed into mathematics, *eg.* AP's and GP's
A^p:	–
A^g:	Proof that the solution is correct
C^p:	Ways of finding new problems
C^g:	Sum the numbers between 1 and 100
E^p:	Sum to n terms $= \frac{n*(first+last)}{2}$
E^g:	The solution 5050

In the CC literature, the focus is often on the product, and virtually all systems in CC discuss the creation of artefacts, rather than processes. One strong motivation behind our development of the FACE model is to emphasize the importance of the process by which an artefact is created in a judgement of creativity. We have done this via our distinction between process and product in each of the four aspects of FACE.

Evaluation in creativity

In the introduction we noted two senses of evaluation which are relevant to creativity: evaluating whether an idea or product is valuable, and evaluating whether a person has been creative. The former, which is judged both internally by a creator and externally by a community, is an essential component of creativity. This notion of evaluation of products as being a key part of the creative process was introduced early on by thinkers such as Wallas [26], who presented one of the first models of the creative process, outlining a four-stage model of creativity: (*i*) preparation, (*ii*) incubation, (*iii*) illumination and (*iv*) verification. The final stage, where an idea is consciously verified, elaborated, and applied may be carried out by either the creator or by the community. Similarly, Parnes [18] introduced evaluation into the creative process in his theory that creativity is a function of knowledge, imagination and evaluation, arguing that the highly creative person must be able to make evaluative judgements about his or her products. This kind of evaluation is also linked to Williams' divergent-productive thinking (described in [16]) in which multiple solutions to a problem are generated and then evaluated to select the best. Mcgraw and Hofstadter account for evaluation in their two-stage model of guesswork and evaluation [17], and refer to the "necessarily iterative process of guesswork and evaluation as the 'central feedback loop of creativity"' [9, p. 451]. Additionally, Maher, Merrick and Macindoe point out that there are numerous characteristics associated with creative design in addition to simply producing novel material, including aesthetic appeal, quality, unexpectedness, uncommonness, peer-recognition, influence, intelligence, learning, and popularity [15]. Thus, the twin processes of generation and evaluation are firmly embedded into notions of creativity. We maintain this distinction in our two complementary models; FACE, which describes generative acts of creativity and IDEA, which describes ways of evaluating the acts. We further reflect notions of internal and external evaluation of a product via our *Aesthetic* and *Framing* aspects of the FACE model. The IDEA model complements these aspects and provides a fine grained approach to evaluation.

Kreitler and Kreitler [14] distinguish between creators and spectators of the creative products and argue that there are two types of creative people, those who create art and those who view it. They have developed a theory of experiencing art consisting of two phases. In the first (perceptual-cognitive) phase, the spectator responds to the work of art, and in the second (motivational) phase, the experience is motivated by psychological tensions which exist in the spectator independently of the current experience. These tensions trigger new tensions in response to the work of art and allow the spectator to give meaning to the art: such meaning develops with the gradual unfolding of different aspects of the artwork. This work has formed the inspiration behind our IDEA model and our thoughts on the cognitive effort required to understand a creative artwork.

Theories of creativity

In view of the difficulties of defining this nebulous concept, some psychologists have moved on from considering 'what is creativity?' to considering 'where is creativity?' Csikszentmihalyi [5] answers this with his systems view of creativity. He sees creativity as an interactive process between three elements: an individual innovator, his or her knowledge about a domain, and a field or community of experts who decide which individuals and products are valued. Of particular interest to us is Csikszentmihalyi's emphasis on the role of the community in which creators operate and how it affects creative outcomes. Uzzi and Spiro [24] also emphasise the role of a community in amplifying (or stifling) creativity. They discuss work which traces the history of key innovations and show that in nearly all cases the creator is embedded in a network of artists or scientists who share ideas and act as each other's critics, creating an atmosphere of cross-fertilisation of ideas. These theories have inspired the social aspects of our model, in particular the framing aspect, in which a creator embeds his or her creation within a field. Attempts at framing may well inspire further innovations in the field. Similarly, our IDEA model is based on theories of how creative work is received. Noting the difficulties experienced by psychologists when trying to define creativity, the fine level of granularity of our models enables us to pinpoint *where* creativity in a particular act has occurred, without having to answer the question of what creativity is.

Gardner [8] holds that an individual must be consistently creative, in order to be considered to be creative. He argues that "the creative individual is a person who regularly solves problems, fashions products or defines new questions in a domain in a way that is initially considered novel but that ultimately becomes accepted in a particular cultural setting." [8, p. 35]. In order to accommodate this criterion, we have designed our FACE model to be used in a cumulative way.

Creative acts and the FACE/IDEA models

We break down two further examples of creativity in order to demonstrate the various aspects of our models. In an attempt to avoid charges of cherry-picking examples which fit our model, we analyse two very different examples in different domains. The first is an example of big-C, transformational, H-creativity in mathematics and the second concerns little-c, P-creativity in general problem solving. It is difficult at this stage to show generality: we invite the reader to similarly decompose other creative acts in order to develop the FACE and IDEA models. Recall that our models are intended to help us to develop and evaluate creative software and are *inspired by*, rather than *models of*, human creativity.

The Basel problem

Euler's solution of the Basel problem in mathematics is a seminal historical episode of human creativity. This is the problem of finding the sum of the reciprocals of the squares of the natural numbers, *i.e.* finding the exact value of the infinite series $1 + \frac{1}{4} + \frac{1}{9} + \frac{1}{16} + \frac{1}{25} + \frac{1}{36} + \ldots$ In Euler's time this was a difficult and well known problem. It had been around at least since Pietro Mengoli posed it in 1650, and had eluded efforts by Wallis, Leibniz and the Bernoulli brothers: Sandifer refers to it as "the best known problem of the time" [20, p. 58]. In 1734 Euler found the solution $\frac{\pi^2}{6}$, solving the problem in three different ways.[2] In his third solution, Euler drew an analogy between finite and infinite series, and applied a rule about finite series to infinite series to get what is referred to by Polya as an "extremely daring conjecture" [19, p. 18]. Euler continued to evaluate this conjecture, and his analogous rule. For instance, he used empirical tests, calculating the value for more and more terms in the series. He also applied the rule to other infinite series, to form predictions which could then be tested: both series with unknown solutions (*eg.* $1 + \frac{1}{16} + \frac{1}{81} + \frac{1}{256} + \ldots = \frac{\pi^4}{90}$) and series where the solution was known (*eg.* Leibniz's infinite series $1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \frac{1}{9} - \frac{1}{11} + \ldots = \frac{\pi}{4}$). In all tests the conjecture and analogous rule held strong.

This creative episode involves several different aspects. Firstly, finding the solution to the Basel problem was a major result. This has inspired our E^g, the expression of a concept. Of even greater value was Euler's discovery of the analogous rule, and in general, ways of converting rules about finite series to rules about infinite series, which – once confirmed – could be applied generally. This has inspired E^p. Euler's proofs that his solution is consistent and sound have inspired A^g. While the modern mathematical concept of infinity was not developed in Euler's time, the concept of infinite series was well established;[3] therefore, his work with infinite series had to fit with the structure already developed. Euler's extended work on the applications and limitations of his analogy and his independent proofs of the solution inspire our framing aspect, F^g. We summarise these creative acts in terms of our FACE model below.

FACE	**Basel Problem**
F^p:	–
F^g:	Euler's extended work on the applications and limitations of his analogy; his independent proofs of the solution; general ways in which analogies can be used in mathematics
A^p:	–
A^g:	Euler's proofs that his solution was sound
C^p:	Ways to find problems such as the Basel problem
C^g:	The Basel problem (Pietro Mengoli)
E^p:	Ways which Euler discovered of converting rules about finite series to rules about infinite series
E^g:	The solution $\frac{\pi^2}{6}$

We see that, in describing how Euler solved the Basel problem, authors such as Polya and Sandifer refer to other creative acts in relevant mathematics communities. They also describe the amount of time Euler took, and the effort he went to in order to justify his result and his methods. They use emotive terms such as "daring" to describe the results. In effect, this is all an attempt to quantify and qualify the impact this creative act had on mathematical society. This motivates our emphasis on impact rather than just value judgement in the IDEA model. In particular, by highlighting the time taken, Polya and Sandifer indicate the level of development Euler's methods went through as he tried and failed repeatedly to find a solution. They also highlight how difficult people had previously found the Basel problem, hence how different Euler's creative act(s) were to the sum of those coming before him. These aspects of the description of impact give us motivation for the branch of the IDEA model that deals with the stage of development software is in, and the utility of understanding exactly the background knowledge available before, during and after the development and execution of the software. In addition, the emotive descriptions highlight that creative acts are intended to affect people's well being. Finally, the description of Euler going to great lengths to justify his methods can be seen as motivation for why we measure the level of cognitive effort that audience members expend in understanding creative acts in the IDEA model. Clearly, Euler was trying to convince people to understand his approach and spend time appreciating the implications it had for mathematics.

[2] For excellent commentary on this work, see [20, pp. 157-165]

[3] Infinite series have been around at least since Zeno.

Duncker's candle task

Duncker's candle task [6] is a cognitive performance test invented by the Gestalt psychologist Duncker, intended to measure the influence of functional fixedness[4] on a participant's problem solving capabilities, and has been used in a variety of experiments concerning creative thinking. The challenge in the candle task is to fix a lit candle on a wall (a cork board) in such a way that the candle wax won't drip onto the table below. One may only use a book of matches, a box of thumbtacks and the candle. The solution, to tack the empty box of tacks onto the wall and sit the candle in the box, is difficult since people typically see the box as a container for the tacks rather than a piece of equipment for the task. Some people find partial solutions, such as tacking the candle to the wall or melting some of the candles wax and using it to stick the candle to the wall. The task is interesting for us since its solution is an example of everyday, little-c, exploratory, P-creativity (other components surrounding the task could be argued to be a different type of creativity, such as Duncker's invention of the problem, which could be seen as H-creative and possibly big-C creativity). We show our decomposition of various creative acts connected to this task in terms of our FACE model below. Since we are interested in the everyday, creative problem-solving aspects in this example we do not consider the IDEA model: there is usually no audience in such contexts.

[4] Functional fixedness is a cognitive bias which limits a person to using an object only in the way it is traditionally intended, for instance a person with a hammer who needs a paper weight, but is unable to see how the hammer could be used for such a purpose.

FACE	Duncker's candle task
F^p:	–
F^g:	An explanation as to how the task was completed
A^p:	–
A^g:	Evaluation of the solution
C^p:	Ways of finding problems like Duncker's candle task
C^g:	Duncker's candle task
E^p:	Techniques to overcome functional fixedness, *eg.* analogical transfer, in which the problem is framed as an analogy, or reorganization of mental categories
E^g:	Tack the box onto the wall and sit the candle in it

Further work and conclusions

While our FACE and IDEA models are not broad enough to cover all potentially creative software systems, we believe that they cover enough to guide and describe the first wave of creative systems. These models constitute a start, rather than endpoint, to our thinking about how to evaluate creativity in machines. This project is ongoing, and we expect to evaluate our two models principally by their utility in describing creative systems: we begin this task in a companion paper [4]. Philosophers of science can also help us to evaluate and compare such measures: recent work has suggested criteria which a good theory should satisfy.[5]

In their analysis of one hundred recent doctoral dissertations on creativity, Wehner *et al.* found a "parochial isolation" and no cross-disciplinary ideas (reported in [23]). They compared the situation to the parable of the blind men who attempt to understand an elephant by touching a different part, thus each building a very different picture of it. We hope that, by drawing inspiration from work in the psychology of creativity, we will help to contribute to a fruitful multidisciplinary approach.

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[5] This paper is not a comparative paper between different frameworks proposed for CC; such a paper, however, would be a very useful contribution.